DISCRETE SOURCE INTERPRETATION OF RECENT HIGH-ENERGY COSMIC GAMMA-RAY MEASUREMENTS

by

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Recent data of Clark Garmire and Kraushaar (1968) obtained with the high-energy gamma-ray detector on board the OSO-3 spacecraft constitute the first convincing measurement of cosmic gamma-rays around 100 MeV. The angular distribution of the events indicate that a large fraction of the flux originates in the galactic disc. One possible interpretation of the results is in terms of the secondary gamma-rays produced through the interactions of cosmic rays with the ambient interstellar gas. Detailed calculations of the expected flux due to this process has been done by various authors using the gas density data obtained through 21 cm Hydrogen line measurements and assuming that cosmic ray intensity pervades the entire galaxy at the level measured locally (Pollack and Fazio, 1963; Ginzburg and Syrovatskii 1964; Hayakawa et. al. 1964; Garmire and Kraushaar 1965; Gould and Burbidge 1965; Fazio 1967).

As discussed by Clark et. al. (1968) the predicted fluxes fall short by more than an order of magnitude in explaining the observed line intensity of 5×10^{-4} photons cm^{-2} sec^{-1} $radian^{-1}$ towards the galactic center as well as the weaker anticenter intensity. Modification of the predicted intensity by increasing the gas density or the cosmic ray flux cannot be clearly ruled out; however, this would imply a drastic modification of the accepted values as well as their galactic distribution.

In this paper we would like to explore the alternate explanation that most of this flux is due to unresolved discrete sources; a possibility suggested by Clark et. al. (1968) as well.

If we start with the low energy data around 4 to 8 keV where the all-sky coverage is most complete, definite predictions and checks can be made regarding the above hypothesis; by unfolding the galactic plane distribution of the x-ray data with the angular response function of the OSO-3 detector the galactic plane profile can be predicted and checked against the results; from the total measured fluxes in the x-ray and gamma-ray region the spectral index can be predicted and compared to the measurements of the power law index in the soft and hard x-ray region; the implied gamma-ray fluxes can be compared to the balloon experiments in the 100 MeV region.

In order to avoid instrumental differences we use the survey of Friedman et. al. 1967 in the 4 to 8 keV region.* The average intensity of x-rays along the galactic plane due to these sources is 4.3 photons cm^{-2}-sec^{-1}-$radian^{-1}$. The observed average gamma ray flux above 100 MeV in the galactic plane is 1.6×10^{-4} photons-cm^{-2}-sec^{-1}-$rad.^{-1}$. If all these gamma-rays are to be accounted

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* In the calculations SCO XR-1 was omitted due to it's soft spectrum and offset position from the galactic plane. (Peterson and Jacobson 1966, Grader et. al. 1968).

for by the extrapolated x-ray power law spectrum, the average differential exponent would be -2.1. Due to the lack of complete spectral coverage of all x-ray sources and uncertainties in the position of the sources, a detailed check of the source spectra is not feasible, however, if we notice that 70% of the galactic x-ray flux is due to TAU XR-1, CYG XR-1 and 8 other sources in the galactic center region, a quantitative comparison can be made for these more intense sources. Table I summarizes the differential spectral index measurements for the well resolved TAU XR-1, CYG XR-1 and the Sagittarius region which contains a number of sources unresolved at the hard x-ray level. As the table indicates, the predicted -2.1 spectra fits quite well with the experimental measurements up to 0.5 MeV, about 2.5 decades short of the gamma rays in question.

The main evidence in favor of the unresolved source model is the galactic distribution of the events. Unfolding the galactic plane distribution of x-rays with the OSO-3 gamma-ray detector response (e-folding angle of 15^{o}) and summing over $\pm$ 15^{o} of the galactic lattitude b^{II} gives the predicted shape of the distribution. On Fig. 1 the OSO-3 results of the galactic plane distribution are plotted with the curve of "de-resolved" x-ray sources extrapolated to 100 MeV using $E^{-2.1}$ differential spectrum. Of the 36 points plotted, 25 of them fall within one standard deviation of the extrapolated x-ray curve as expected for a good fit.

The implied fluxes of gamma-rays above 100 MeV for these sources would be 10^{-4} to 5×10^{-5} photons cm^{-2}-sec^{-1} which are slightly higher than the experimental upper limits of 10^{-4} to 3×10^{-5} photons cm^{-2}-sec (Cobb et. al. 1965, Frye and Smith 1966, Fichtel et. al. 1968, Fazio et. al. 1968). The only positive flux measurement at this energy was reported by Duthie et. al. (1966) at a direction around Cygnus XR-1 as $1.5 \pm .8 \times 10^{-4}$ photons cm^{-2}-sec^{-1} which is close to the value of 9×10^{-5} photons cm^{-2}-sec^{-1} obtained by extrapolating the x-ray flux with a -2.1 differential index. However, it should be pointed out that Frye and Wang's (1967) data indicate no such flux. In view of the fact that the flux values and limits are quite sensitive to the energy response as well as the angular resolution of the apparatus used, factors of 2 discrepancy between various experiments are quite reasonable.

The fact that one single spectral index may account for the fluxes from x-ray to high-energy gamma-ray region implies that the mechanism responsible for this emission could not be synchotron radiation because of the extremely short lifetimes of electrons radiating the gamma-rays.

In conclusion, although it is naive to expect all the x-ray sources to behave identically, assuming that on the average they have a -2.1 differential index up to 100 MeV region would enable us to explain the observed gamma ray flux and still retain the accepted values of galactic cosmic ray flux and ambient gas distribution. The flux levels of gamma-rays predicted for these sources are close to the sensitivity threshold of the present day balloon borne detectors and should yield positive measurements in the near future.

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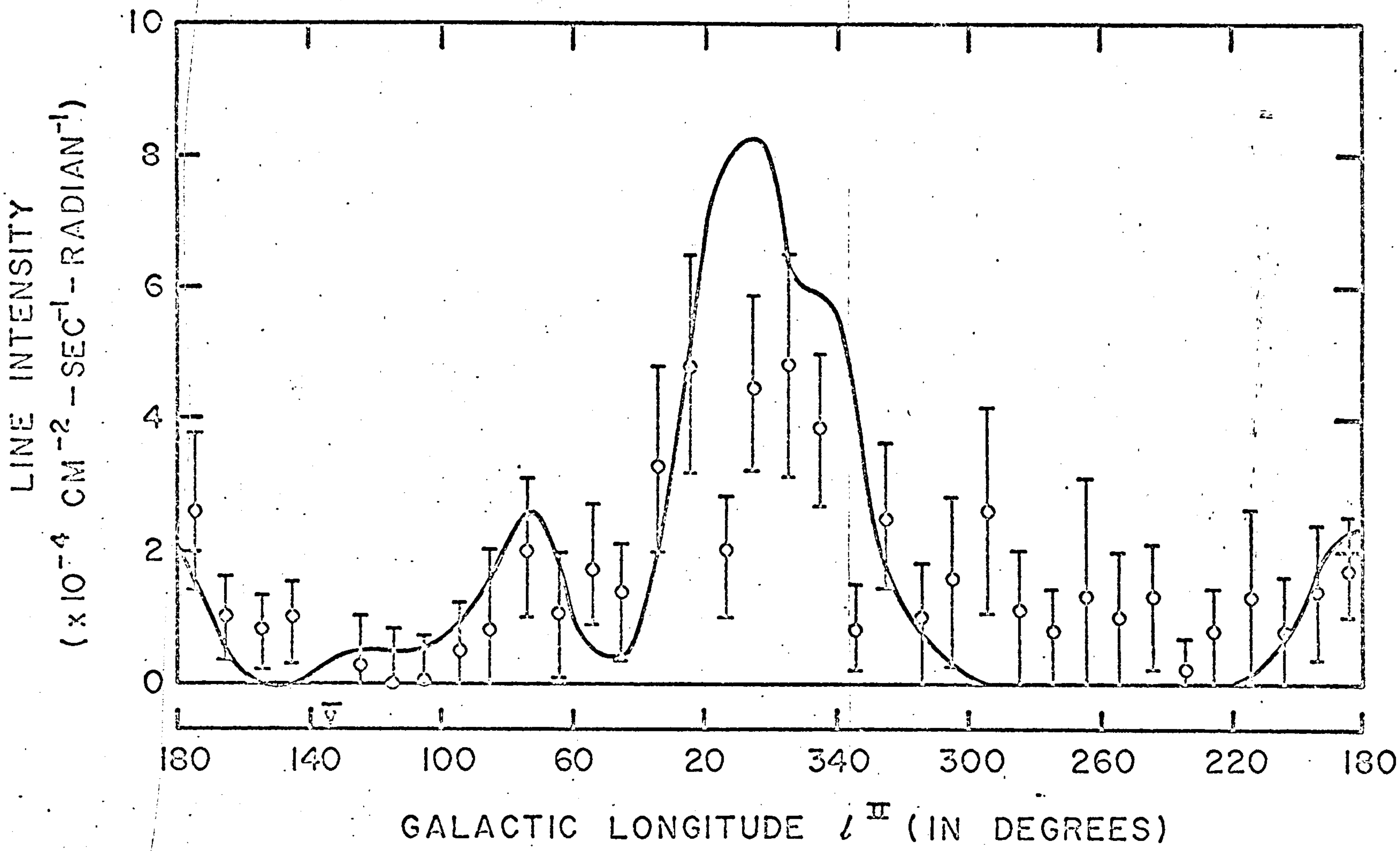
TABLE I

Summary of the differential power law index measurements of the TAU XR-1, CYG XR-1 and the Saggitarius region.

Source	Differential power law index		Reference
TAU XR-1	$-1.93 \pm .05$	(2-20 keV)	Holt et. al. 1968
	-2.3	(5-40 keV)	Grader et. al. 1966
	-2.0 ± 0.3	(10-100 keV)	Riegler et.al. 1968
	-1.91	(10-250 keV)	Peterson et.al. 1968
	$-2.19 \pm .08$	(30-500 keV)	Haymes et. al. 1968a
CYGNUS XR-1	-2.5 ± 0.6	(10-100 keV)	Riegler et.al. 1968
	-2.62 ± 0.5	(20-130 keV)	Bingham & Clark 1968
	-1.93 ± 0.2	(10-250 keV)	Peterson et.al. 1968
	-1.93 ± 0.2	(30-500 keV)	Haymes et. al. 1968b
	$-2.2^{+0.3}_{-0.2}$	(1-10 keV) *	Rappaport et.al. 196
SAGITTARIUS REGION	$-2.0 \pm .2$	(10-100 keV)	Buselli et.al. 1968
	-2.6 ± 1.0	(10-100 keV)	Riegler et.al. 1968
	-2.1 ± 0.3	(30-500 keV)	Haymes et. al. 1968c

*The data well resolves the Sagittarius region, the quoted value is for the strongest source GX 5-1.

Fig. 1 The solid line is the predicted gamma-ray intensity distribution above 100 MeV with $E^{-2.1}$ extrapolation of the x-ray sources. The points are the results of the OSO-3 gamma-ray detector (Clark et. al. 1968).



LINE INTENSITY
(x 10^{-4} CM^{-2} - SEC^{-1} - RADIAN^{-1})
10
8
6
4
2
0
180
140
100
60
20
340
300
260
220
180
GALACTIC LONGITUDE l^{II} (IN DEGREES)